InTlSb REPORT

InTlSb for Long-Wavelength Infrared Photodetectors and Arrays

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InSb and InTlSb Progress Report

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The heteroepitaxial narrow-gap semiconductors on Si or GaAs substrates offer the possibility of monolithic integration of detectors and readout circuits in the infrared focal plane arrays (IRFPAs). This structure can avoid the problems of a complicated etch-thinning process and indium bump displace in the hybrid case. This structure permits the production of a large-area FPAs with high reliability and low cost. The purpose of this project is to develop III-V IRFPA on InSb, GaAs, Si substrates, specially detectors made from $In_{1-x}Tl_xSb$ material system. The devices are of potential in the long wavelength (8-14 um), particularly in the application of thermal imaging, as MCT materials suffer from poor composition uniform over large areas and thermal stability. As a preliminary step towards InTlSb photovoltaic detectors, it is necessary to establish a reliable procedure to fabricate InSb photovoltaic detectors. Hence, in this report we will briefly outline the development and fabrication processes of InSb photovotaic detectors grown by LP-MOCVD at CQD.

The InSb epitaxial layers on the n^+-InSb substrate have been grown by LP-MOCVD at a temperature of about 450^o C and a pressure of 76 torr using trimethylindium (TMI) and trimethylantimony (TMSb) as sources of In and Sb, respectively. The p^+-i-n^+ structures are obtained by using Zn and Sn for p- and n-type dopants, respectively. The doping levels are about $5x10^{18}$ cm^{-3} for p-type and $5x10^{16}$ cm^{-3} for n-type, respectively. The advantage of PIN structures is to increase quantum efficiency as the depletion region is very narrow due to high doping. The structure is shown in Figure 1.

The first step in fabricating photodetectors is to etch the mesa structure. This is accomplished by using photolithography and chemical etching techniques. The sensitive area is finally defined by the etch process. The mesa size is 200 um x 200 um including the contact area 100 um x 100 um. In the process the Shipley 1813 photoresistance is used. The thickness is about 1 um which is measured by an alpha-step mechine (Tencor). After prebake at 80 ^{o}C it is exposed by UV light (Karl-Suss) in 10 seconds and developed by Shipley Developer 351 for about 1 min.. The postbake is carried out at temperature 120 ^{o}C for 30 min.. The etching solutions are lactic and nitric acids at room temperature. The depth of such a mesa structure is about 4 um. The final mesa structure is displayed in photograph I. The detail process steps are shown in Figure 2 (a) - (e).

The next important step is to make metallization on the surface of InSb epitaxial layers, which is realized by an electron-beam-evaporator at CQD. At first, only one layer of Au was selected as contacts to InSb. The thickness is about 2000 Å . After then it is annealed at the temperatures between 150 ° C and 380 ° C in the atmosphere of N_2 gas for about 1 min. to 4 min. . The problem arising from such contacts is lift-off during the Au-bonding process. The Au-ball bonding is realized by using a Universal Ball Bonder (Kullcke and Soffa Industries, Inc., Model 4124) at CQD. Therefore, Ti/Au contact is suggested to make contacts with InSb as Ti is strong adhesive with the semiconductor surface and also chemical stability. It can form good ohmic contact with both n- and p-type materials. The photolithography techniques are employed to get contact pattern. The etching solutions for Au ($KI:I_2:H_2O$) and Ti (HF) are selective. Furthermore, the solutions for Ti (HF) and InSb (lactic:nitric) are also selective. Thus, it provides us a good way to protect the surface of InSb when the contact pattern is made by chemical etching. The detail processes are shown in Figure 2 (f) - (j).

Packages (bonding and mounting) are carried out at CQD. The chips are mounted on the heat-sink with coated-In at a temperature of 160 °C in an atmosphere of mixed gases 90% N_2 and 10% H_2 for about 2 min.. Au-ball bonding is accomplished by the Au-ball bonding machine. Since InSb material is mechanically quite soft, special care has to be taken by adjusting the force, power

and time in bonding and temperature. In this experiment a temperature of 137 ° C and the 500 ms are selected. However, the bonding point is made on the sensitive area as shown in photograph II.

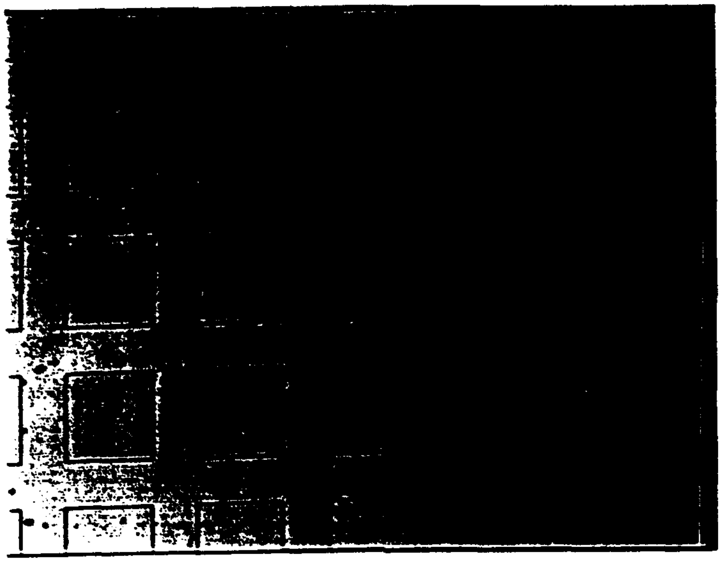
The current-voltage characteristics are shown in Figure 3. The dark currents are quite high at low temperatures. In order to analyze the dart current mechanisms in the devices, temperature-dependent R_0A product has been measured within a small current of uA order between 77 K and room temperature. The results are shown in Figure 4. The large dark currents are probably due to both trap-assistant tunneling and band-to-band tunneling processes. Hence, further reduction of doping levels and background doping levels are necessary to reduce dark-currents.

The spectral response measurements are carried out by a Mattson Fourier transform infrared spectrometer at low temperatures. The temperatures are between 77 K and room temperature. The results are shown in Figure 5. The InSb photodetector has photoresponse till 6 um at 200 K.

So far we have discussed the InSb photodetectors with PIN structures. In order to approach the InTlSb photovoltaic devices, the InSb/InTlSb PIN Heterostructures are suggested here as shown in Figure 6. The doping level for p-type is about 5×10^{18} cm^{-3} and n-type 5×10^{16} cm^{-3}. The processing is almost the same as InSb photodetectors. The difference is only that we use one-side contact to simplify the processing. The sensitive area is about 400 um x 400 um including 150 um x 150 um contact area. The surface is quite rough with a difference about 0.3 um (see photograph III and IV). However, the Ti/Au metals make contact with the surface quite well so that the bonding is made by using the Au-ball bonding machine. The I-V characteristics and photoresponse are shown in Figure 7, and Figure 8, respectively. It has very large dark currents although we have observed photoresponse. However, the response is only till 5.5 um indicating that there is no photoresponse of InTlSb material. This is agreeable with the results of X-ray diffraction measurements (Philips) as it does not show any Tl incorporation in this material. Hence, further improvements in the material growth are suggested.

In summary, we have successfully demonstrated the InSb photovoltaic detectors grown by LP-MOCVD. The photoresponse has been observed till 6 um at 200 K. The temperature-dependent R_0A products show that there are quite large dark currents at low temperatures. So, further reduction of dark currents are necessary. On the other hand, we are successful in processing the InSb/InTlSb PIN heterostructures.

At present, it is important to reduce dark currents and, hence, to increase device performances. Apart from the reduction of doping levels, the passivation of InSb surface by SiO_2 is necessary. On the other hand, the dielectric layer SiO_2 makes the off-sensitive area bonding possible (see mask I, II and III). Thus, high yields can be obtained. Additionally, the calibration with a blackbody source for IR photodetectors is needed.



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Photograph I: InSb Mesa Structure

Photograph II: InSb Photodetector

Figure 1

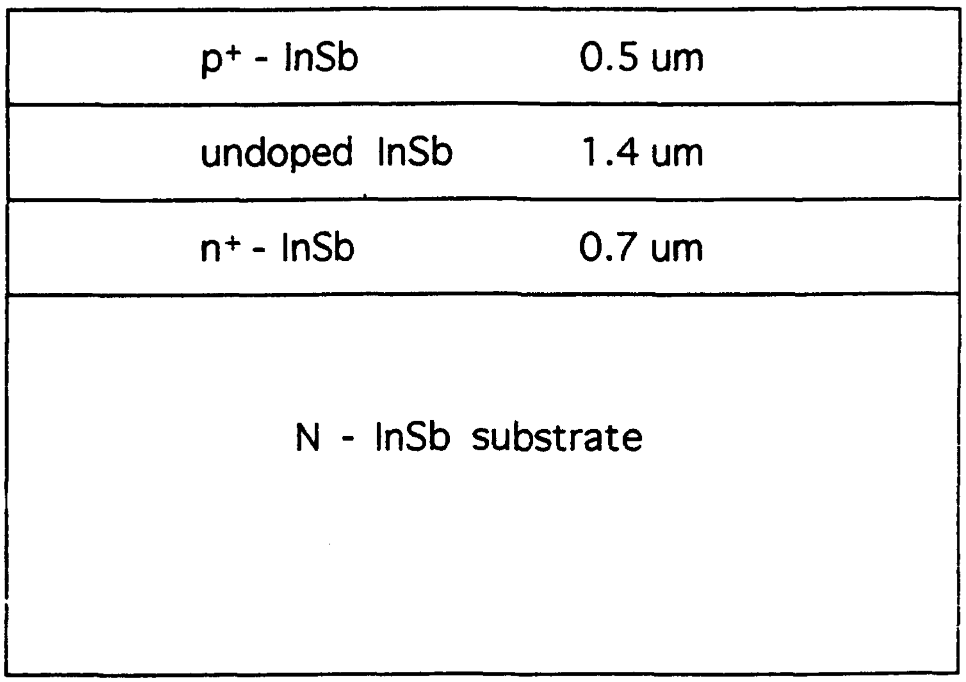


Figure 2

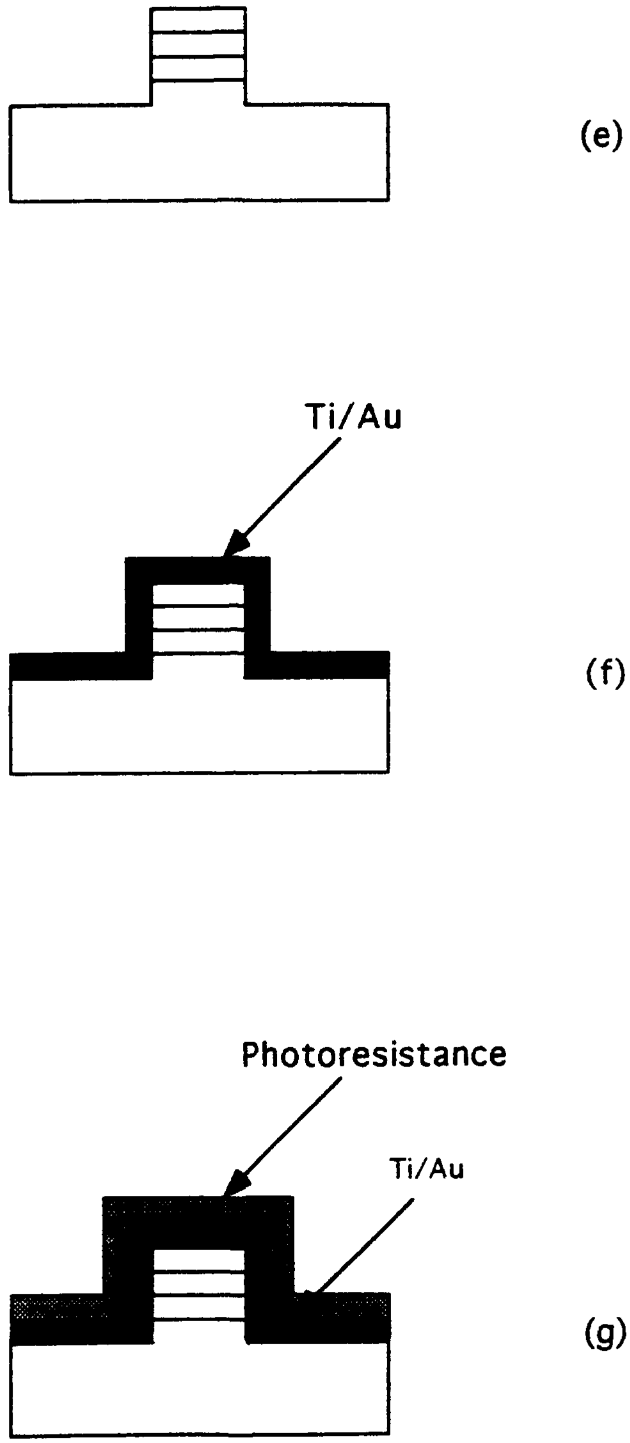
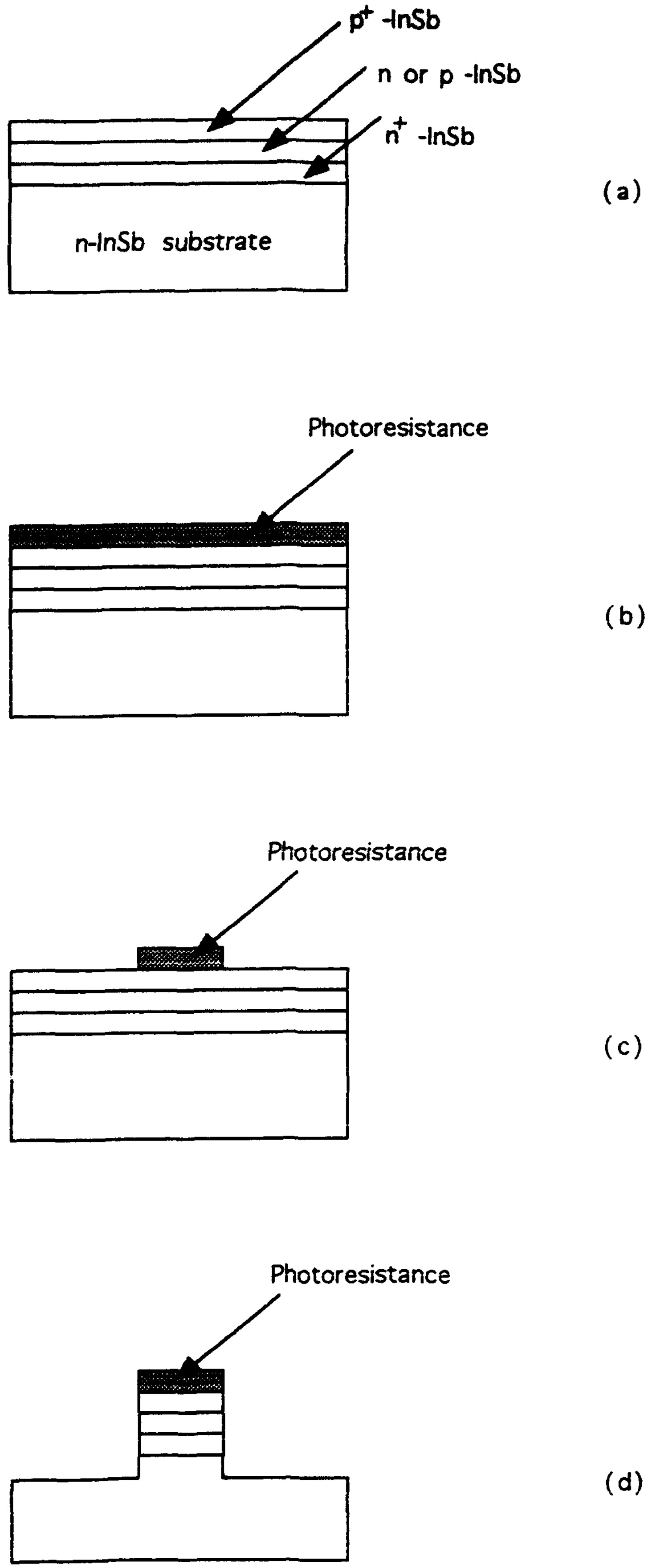


Figure 2



p^+ -InSb
n or p -InSb
n^+ -InSb
n-InSb substrate
(a)
Photoresistance
(b)
Photoresistance
(c)
Photoresistance
(d)

Figure 2

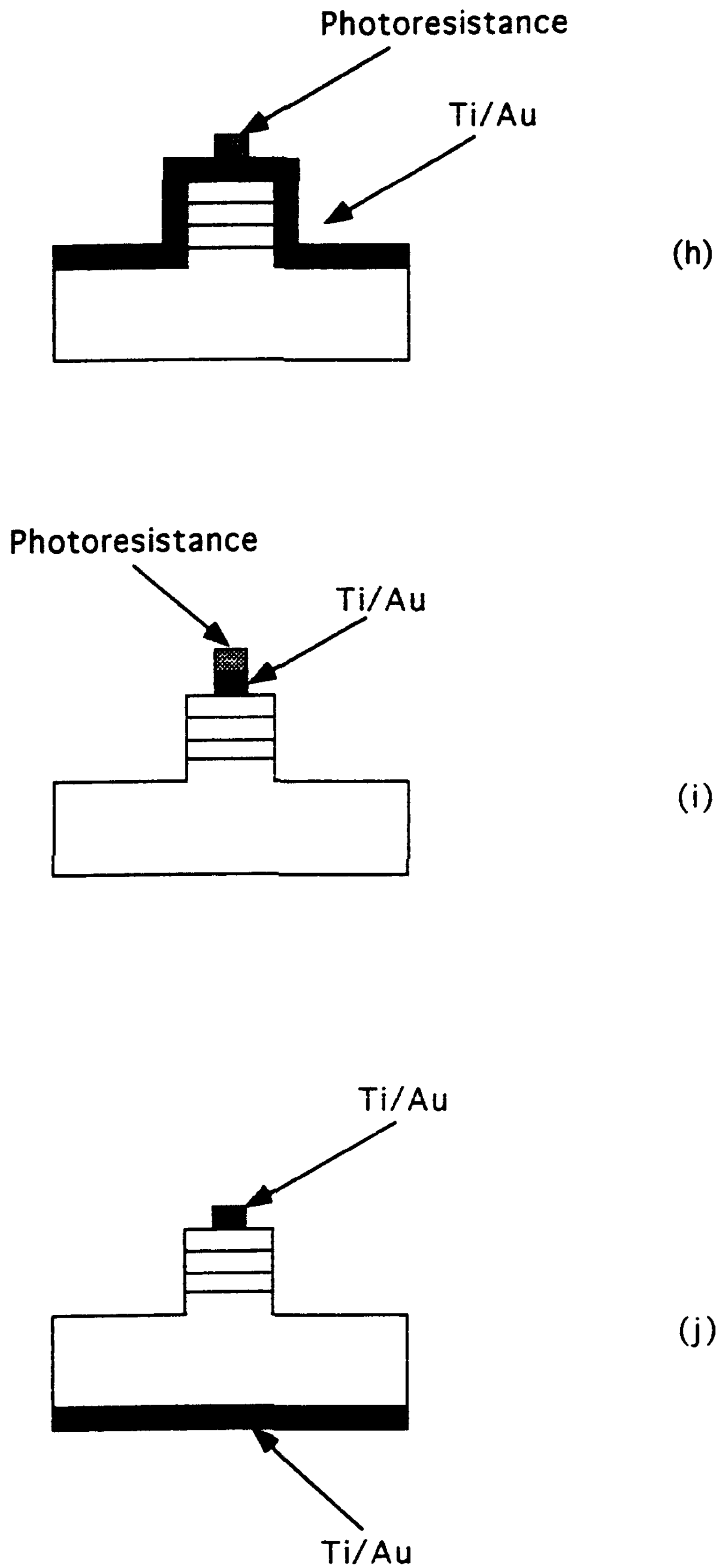


Figure 3

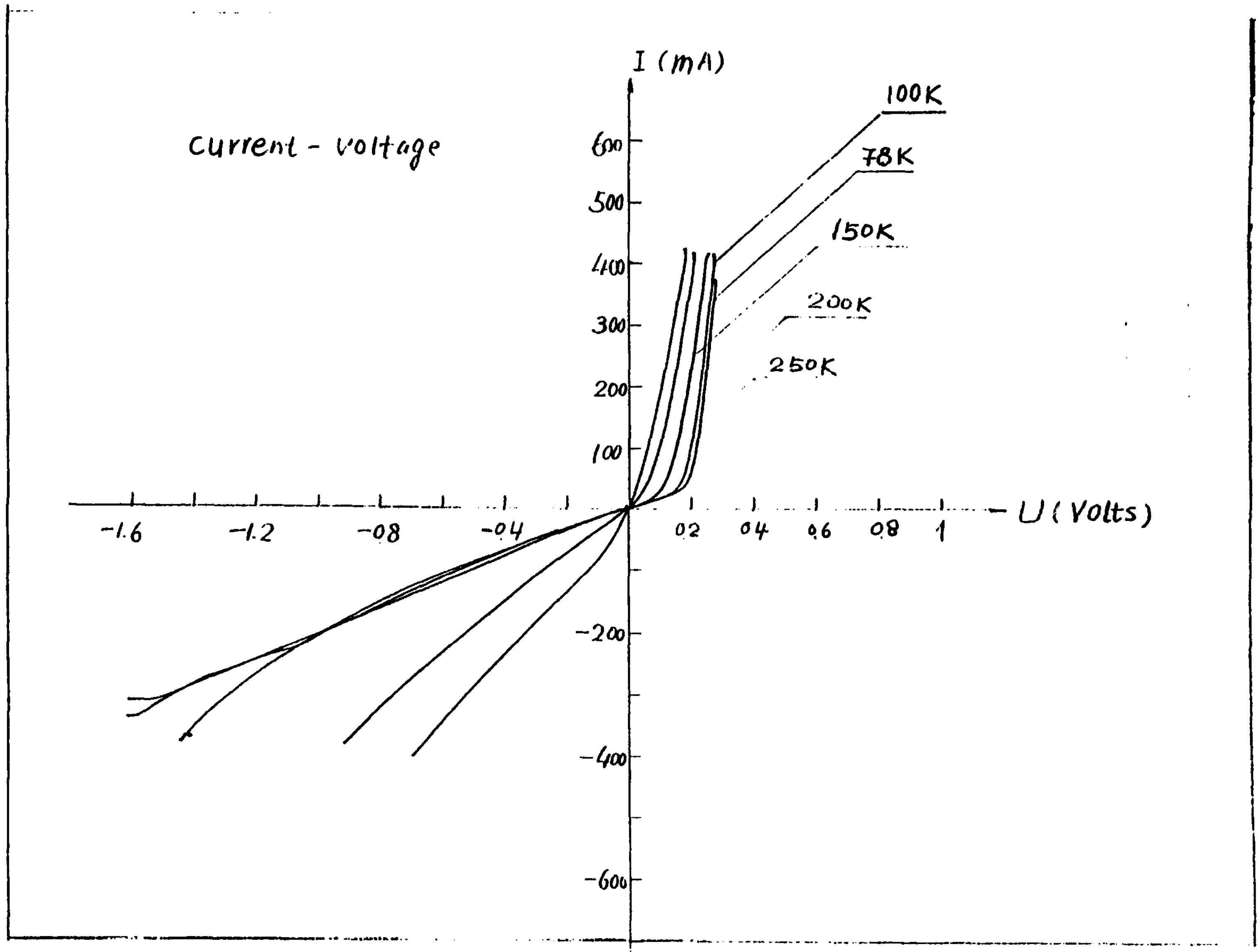

current - voltage
I (mA)
U (Volts)
100K
78K
150K
200K
250K
600
500
400
300
200
100
-200
-400
-600
-1.6
-1.2
-0.8
-0.4
0.2
0.4
0.6
0.8
1

Figure 4

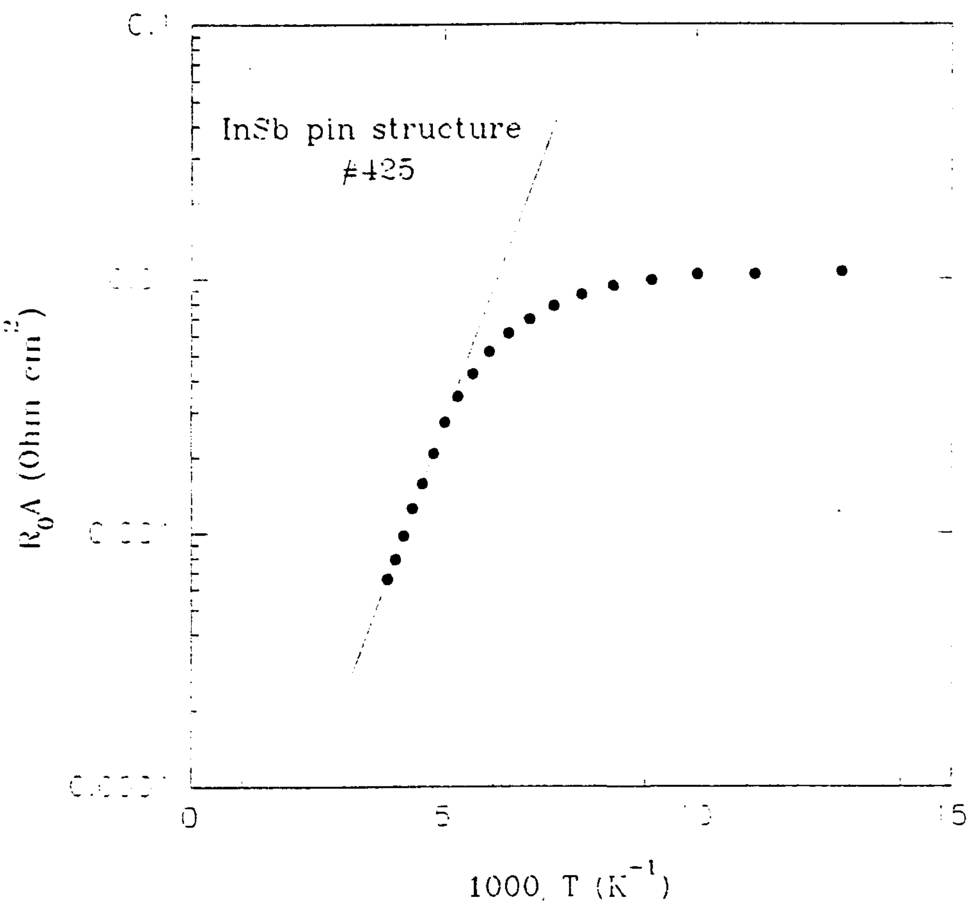


Figure 5 (a)

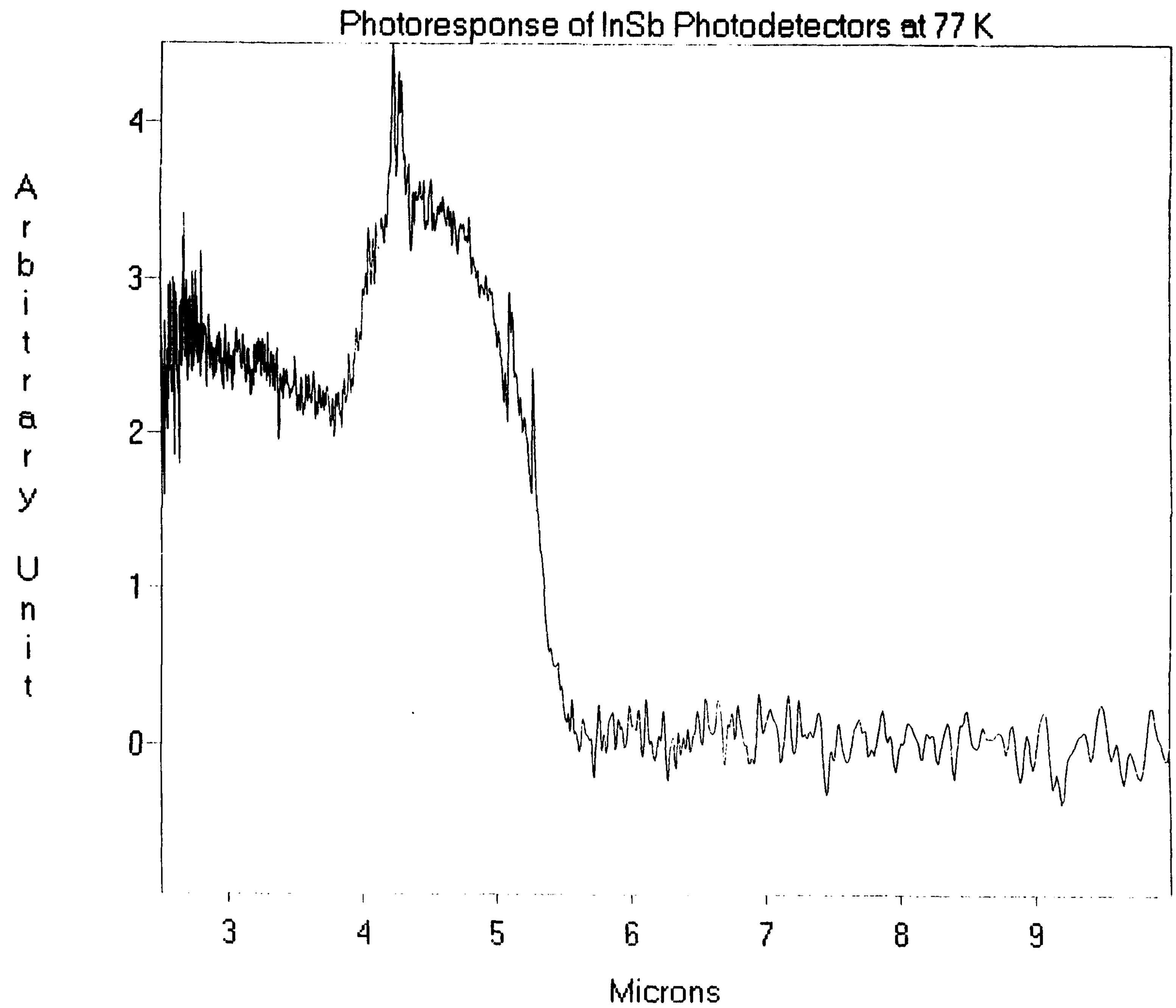
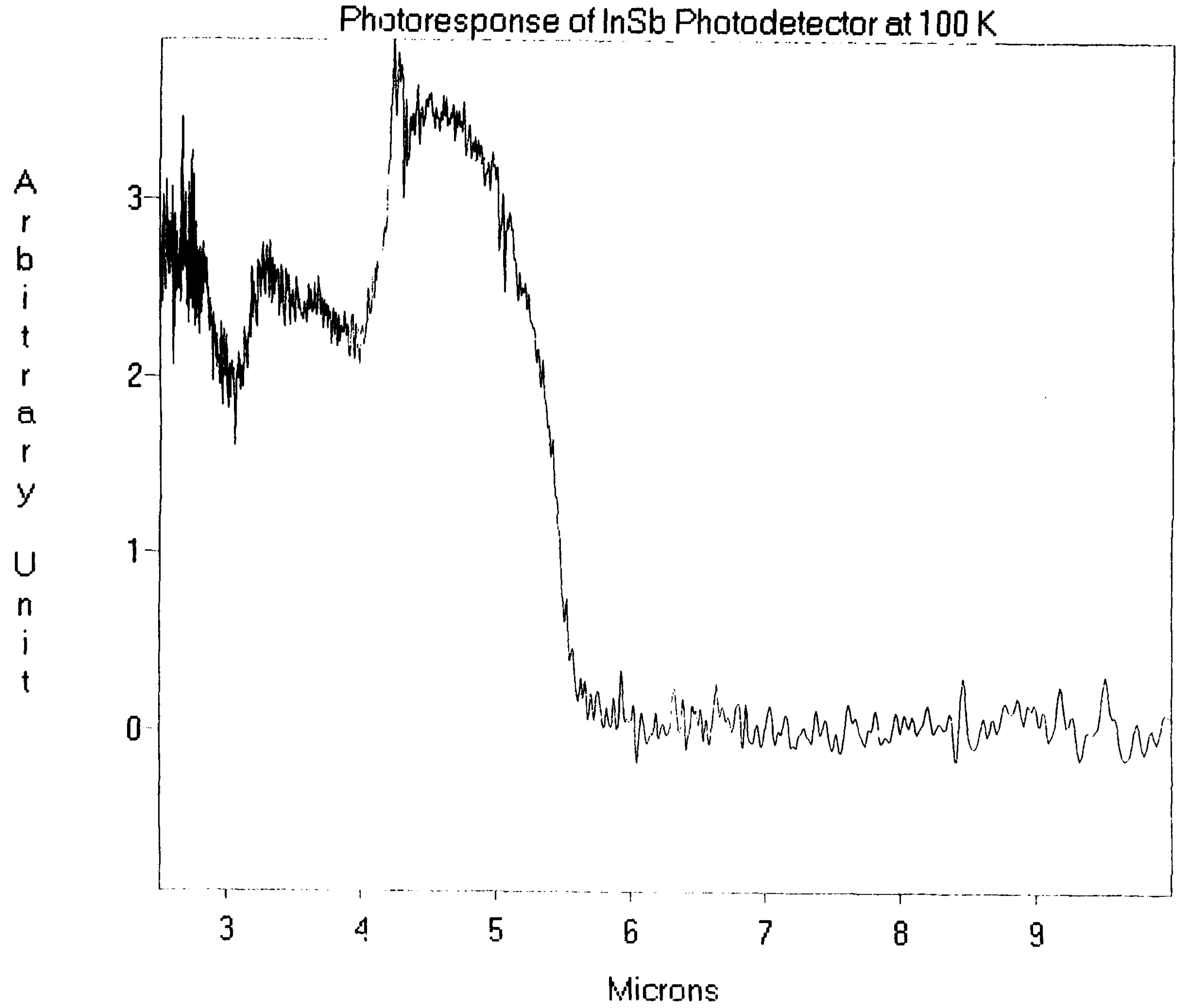

Photoresponse of InSb Photodetectors at 77 K
Arbitrary Unit
0
1
2
3
4
3
4
5
6
7
8
9
Microns

Figure 5 (b)



Photoresponse of InSb Photodetector at 100 K
Arbitrary Unit
0
1
2
3
3
4
5
6
7
8
9
Microns

Figure 5 (c)

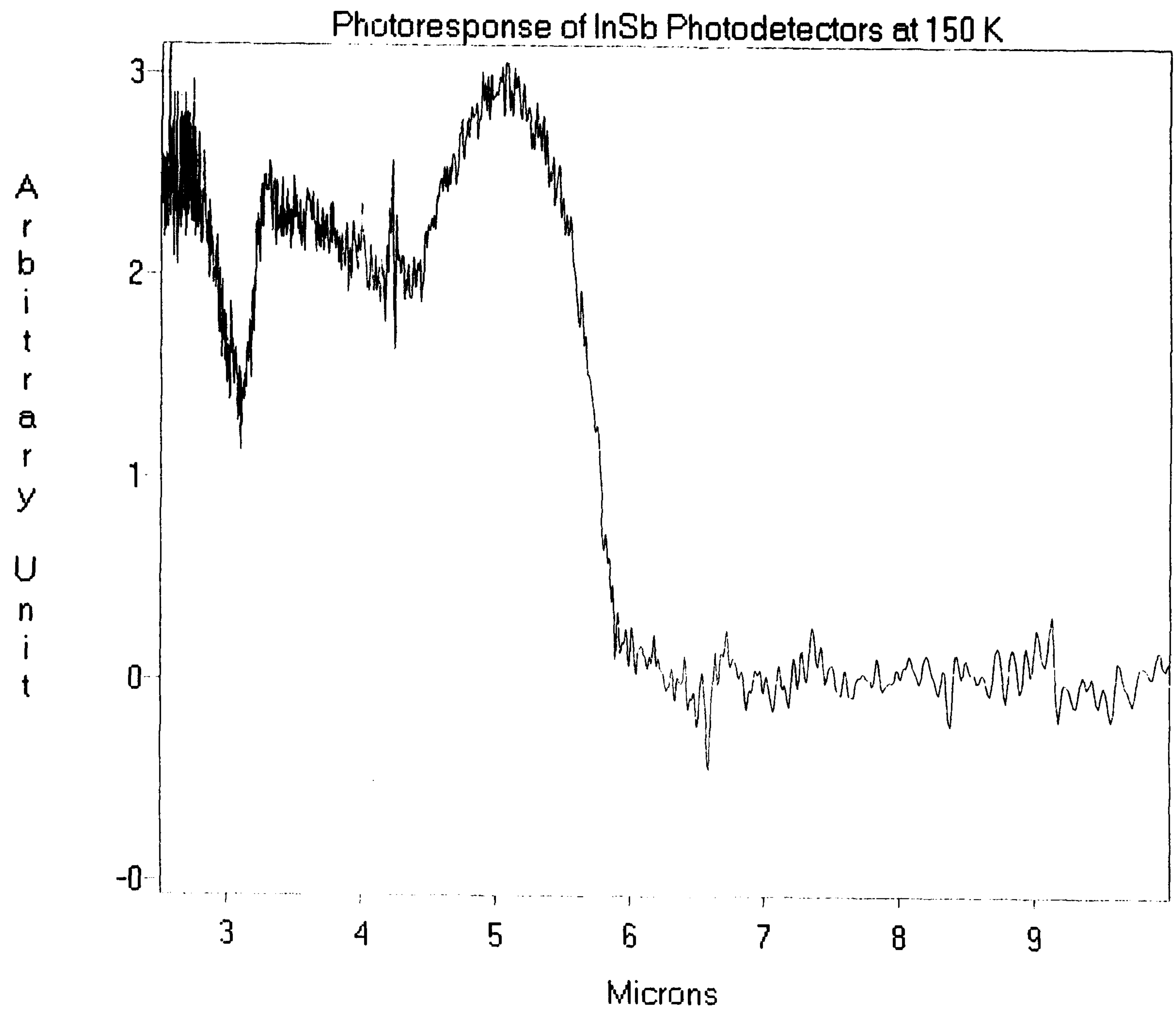
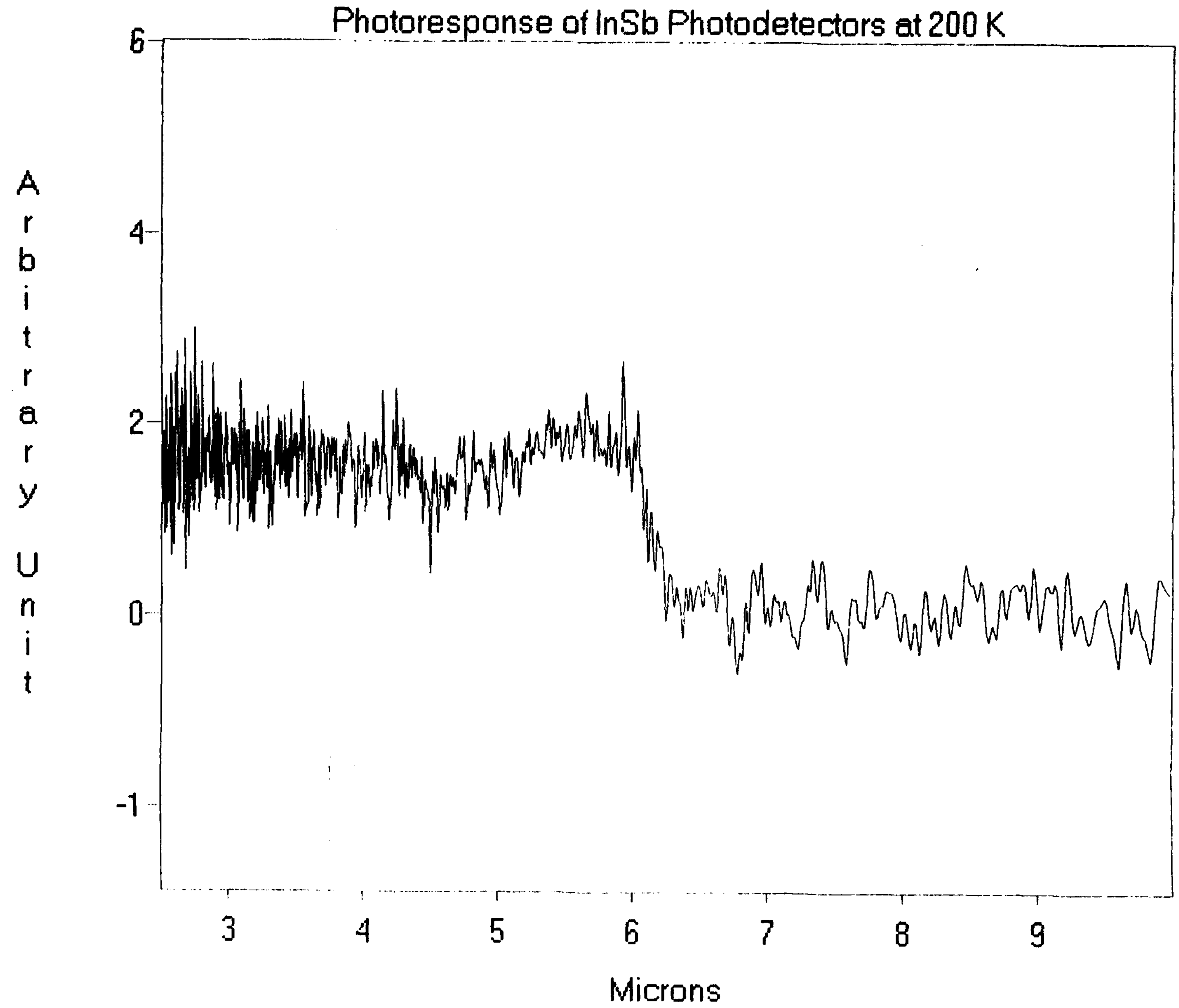
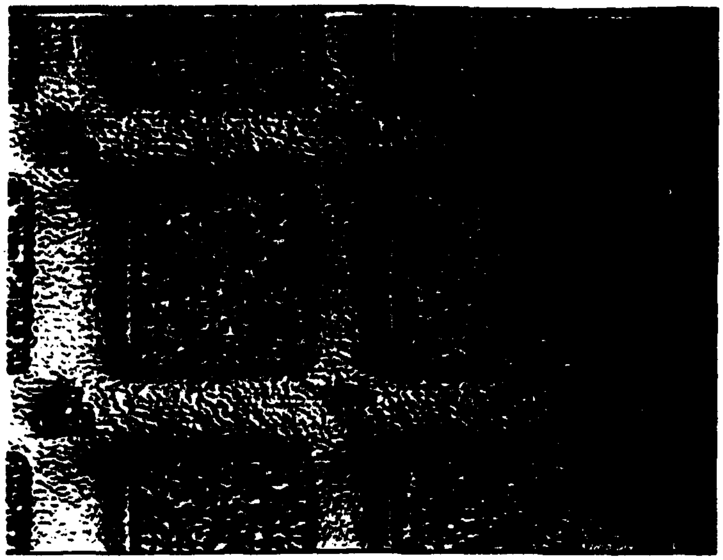
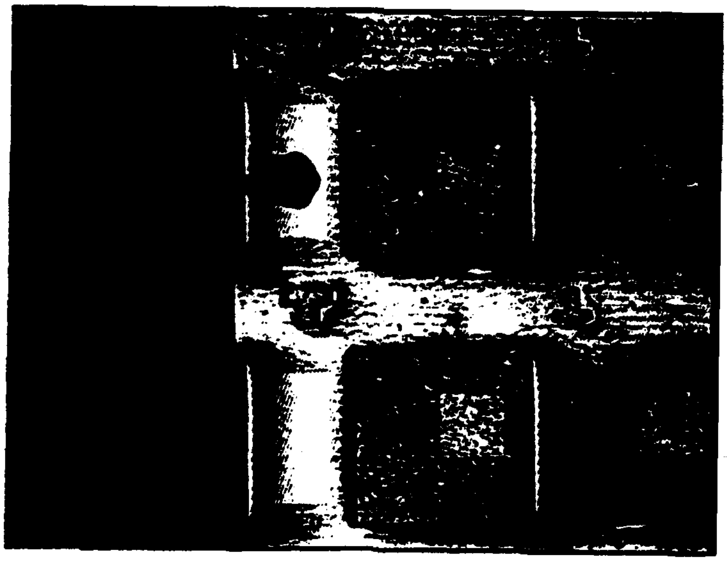

Photoresponse of InSb Photodetectors at 150 K
Arbitrary Unit
3
2
1
0
-0
3
4
5
6
7
8
9
Microns

Figure 5 (d)


Photoresponse of InSb Photodetectors at 200 K
Arbitrary Unit
6
4
2
0
-1
3
4
5
6
7
8
9
Microns



Photograph III: InTlSb Mesa Structure



Photograph IV: InTlSb Photodetector

Figure 6

p^+ - InSb	0.08 um
undoped InSb	1.0 um
undoped InTlSb	2.0 um
undoped InSb	1.0 um
n^+ - InSb	1.0 um
N - InSb substrate	

Figure 7

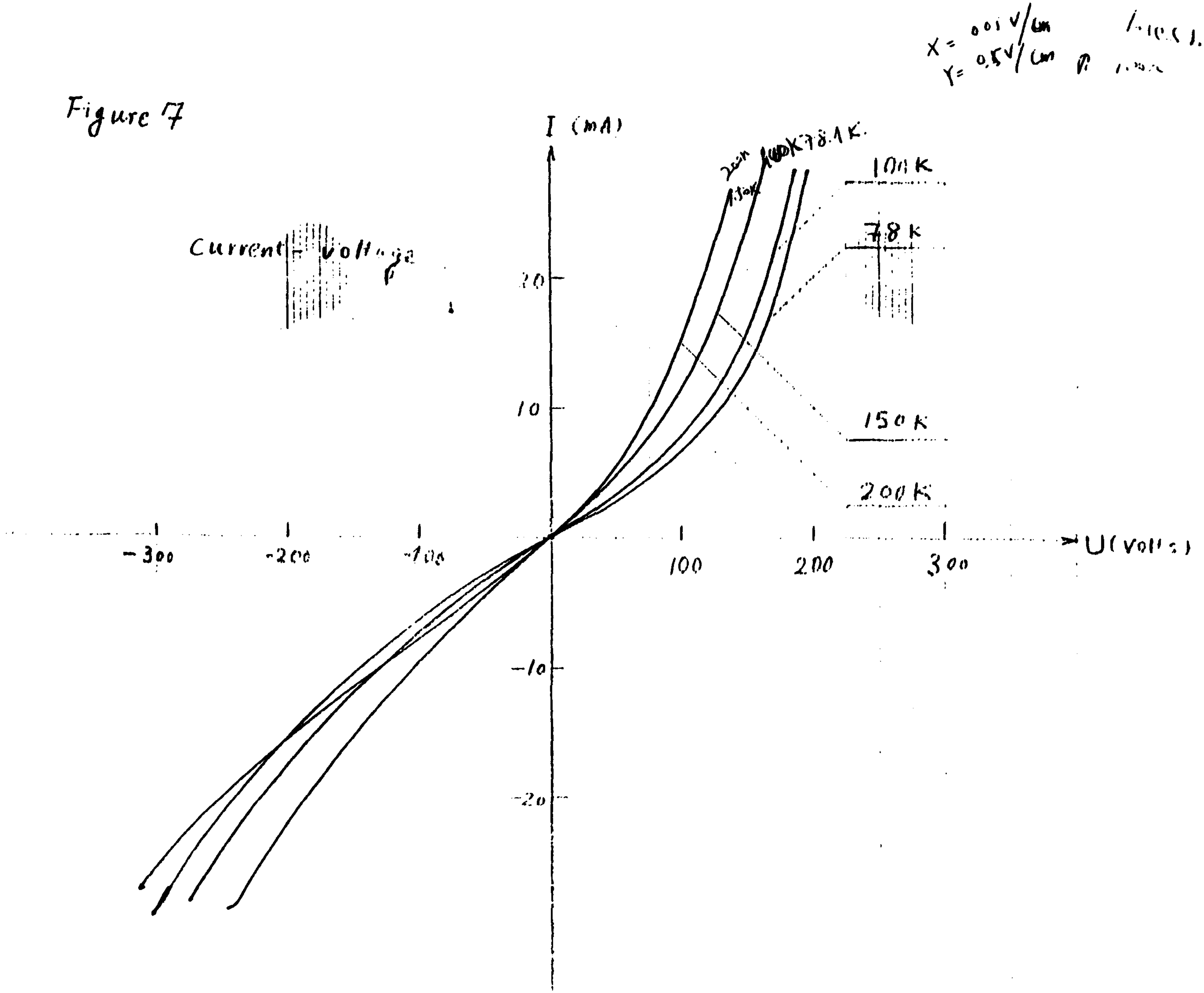
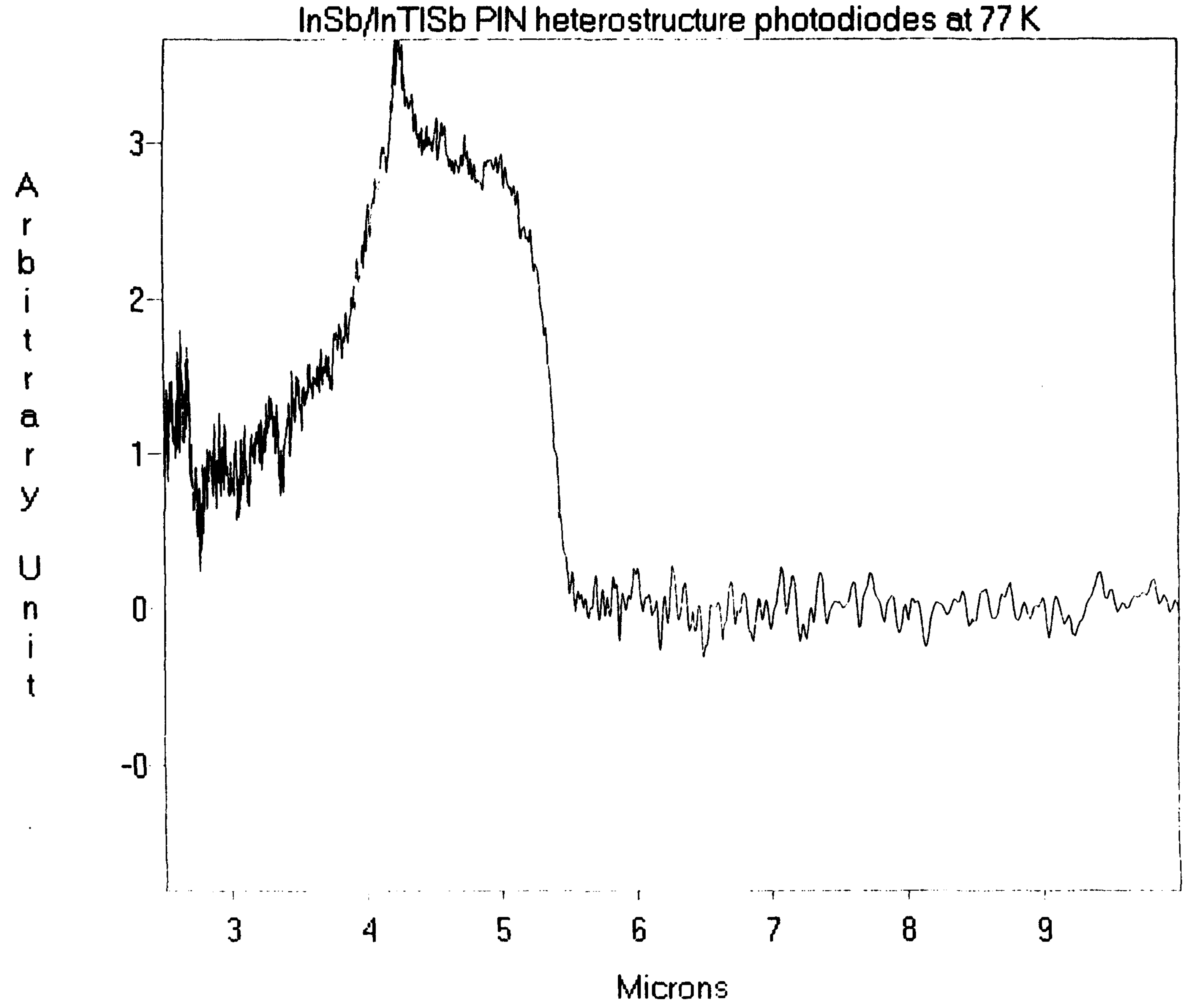

X = 001 V/cm
Y = 0.5 V/cm
Current-Voltage
I (mA)
U (volts)
100K
78K
150K
200K
20
10
-10
-20
-300
-200
-100
100
200
300

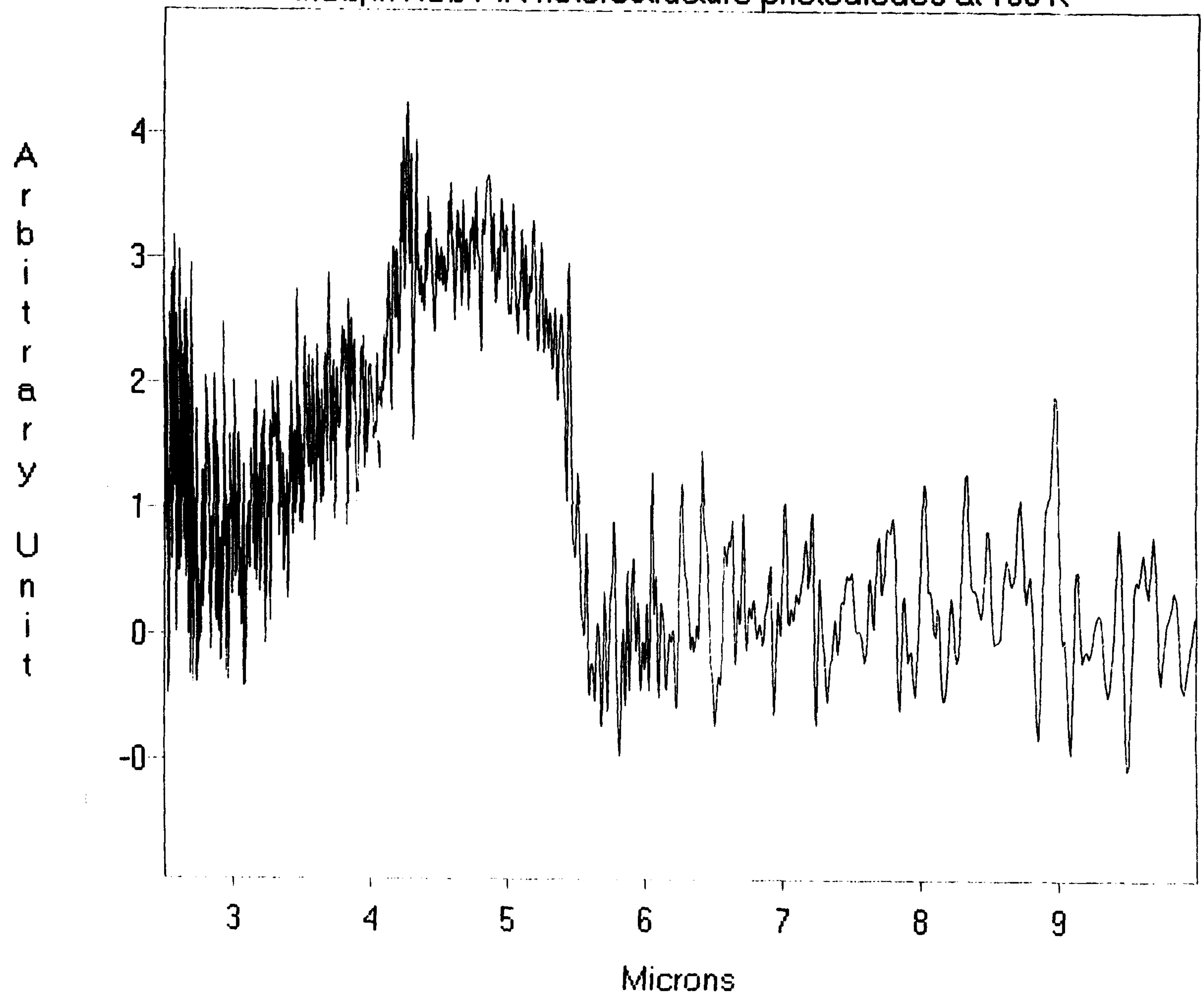
Figure 8 (a)



InSb/InTISb PIN heterostructure photodiodes at 77 K
Arbitrary Unit
3
2
1
0
-0
3
4
5
6
7
8
9
Microns

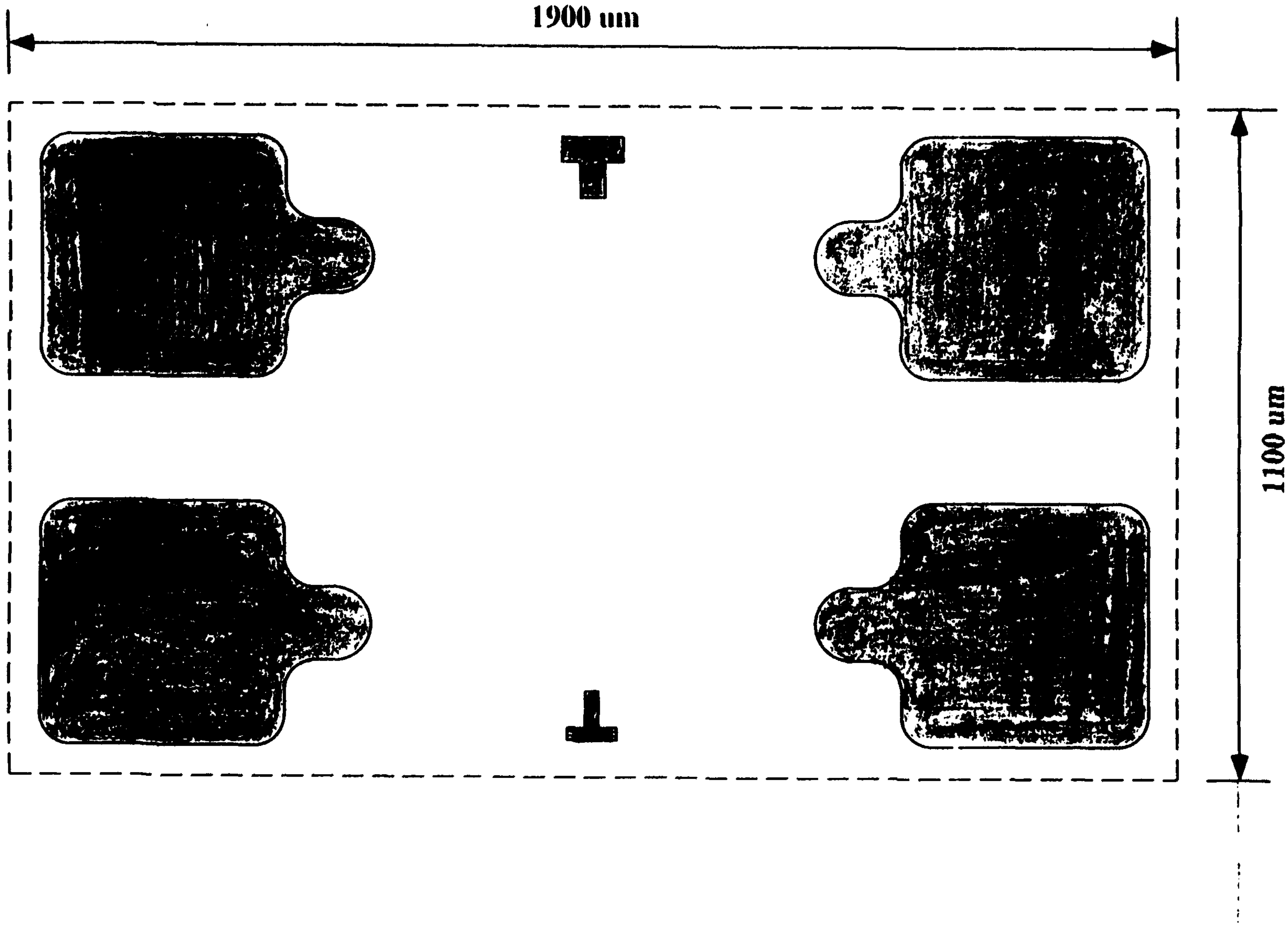
Figure 8(b)

InSb/InTlSb PIN neterostructure photodiodes at 100 K

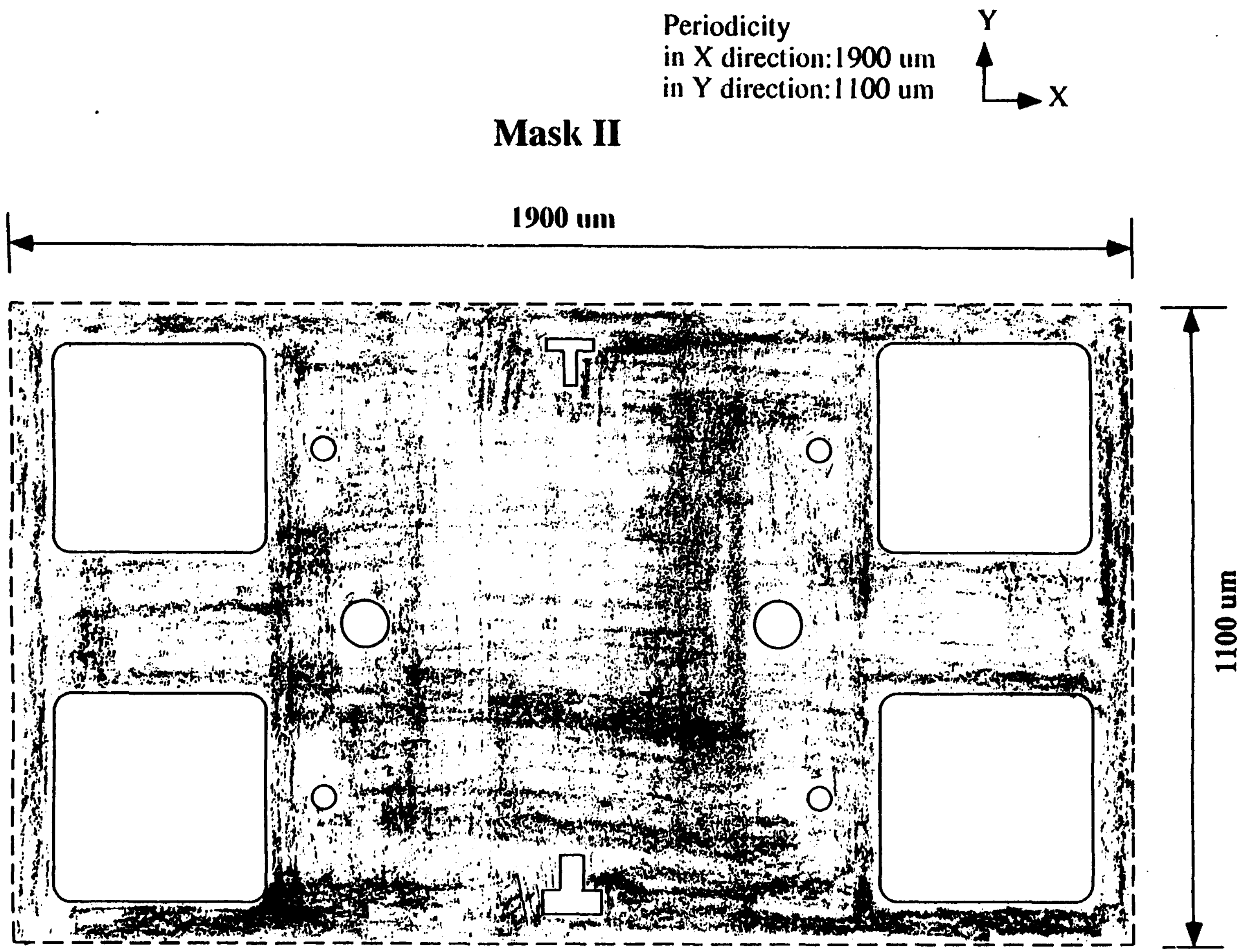


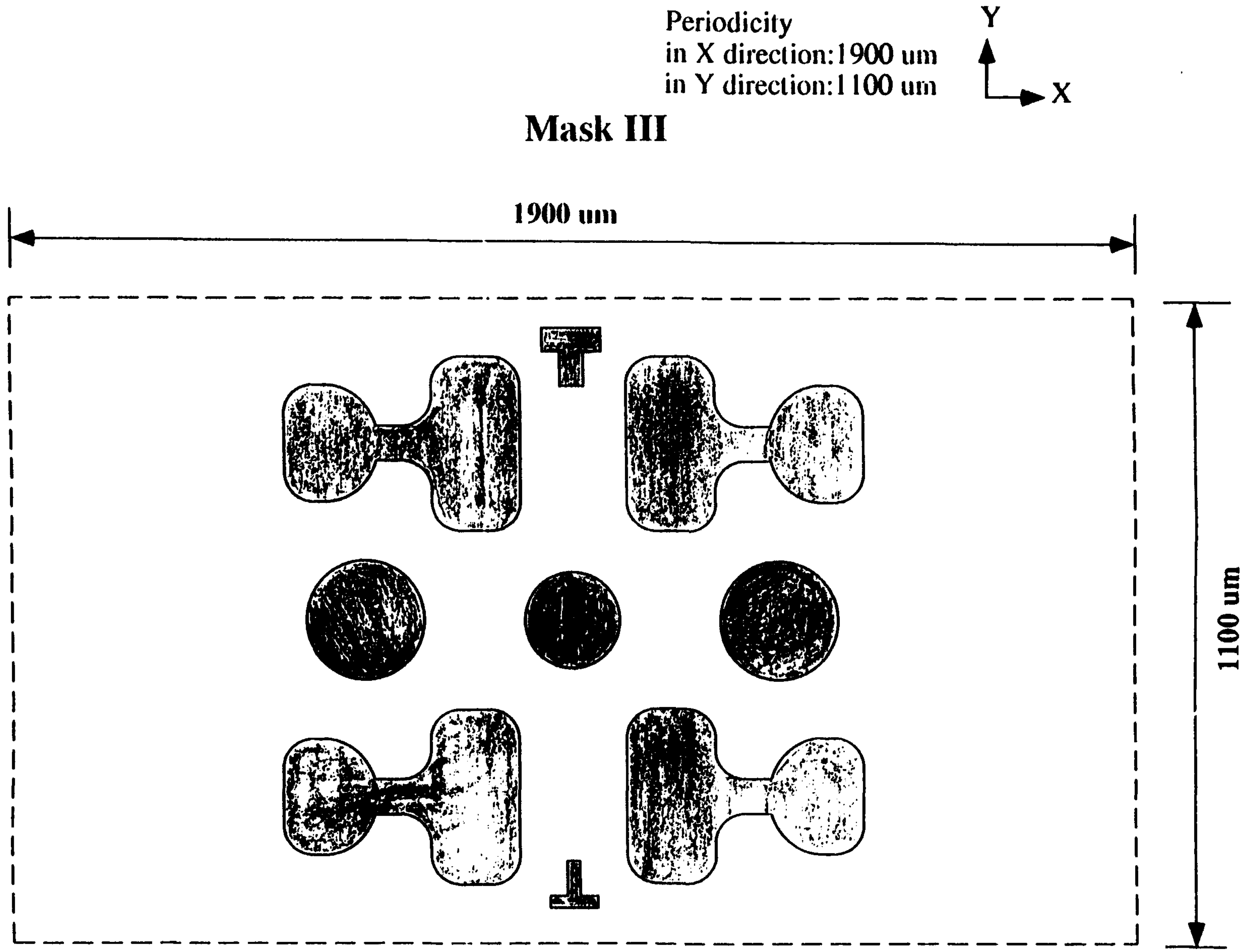
Mask I

Periodicity
in X direction:1900 um
in Y direction:1100 um



Mask II


Periodicity
in X direction:1900 um
in Y direction:1100 um
Y
X
1900 um
1100 um


Periodicity
in X direction:1900 um
in Y direction:1100 um
Y
X
Mask III
1900 um
1100 um